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The Department of Defense provided $6,000,000 of FY93 funds towards research equipment purchases for the completion of research facilities. These facilities are devoted to research in semiconductor electronic materials and devices.

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ABSTRACT

This report summarizes the actions and progress in equipping the microelectronics and materials research programs at The University of Texas at Austin. The Department of Defense provided $6,000,000 towards research equipment purchases for the completion of the research facilities. The University of Texas at Austin had already invested $34 million to build a new 135,000 square foot facility and partially equipped it using $10 million. The $6.0 million of DoD funds completed the acquisition of the equipment necessary to fully utilize the new facility. The equipment has been used to conduct research in the areas of advanced epitaxial growth techniques involving remote-plasma enhanced growth, laser enhanced growth, and rapid thermal processing applied to chemical vapor deposition; advanced epitaxial growth techniques for multilayer, compound semiconductor heterostructures using molecular beam epitaxy and organometallic vapor phase epitaxy techniques; interconnect metallization; metal/polymer packaging structures; structured microwave impedance surfaces; nanoheterogeneous amorphous thin films; and spin valve effects.

I. **FINAL TECHNICAL REPORT**

Microelectronics and Materials Research Equipment

Grant Number F49620-93-1-0401

The purpose of the $6,000,000 from the Department of Defense was for research equipment to complete the equipping of key research facilities and to provide a state of the art environment for microelectronics and materials research programs that will continue to make significant contributions to the nation's scientific, technological, and defense posture.

At The University of Texas at Austin (UT-Austin), a major thrust in microelectronics was initiated in the early 1980's, resulting in the addition of 11 faculty specializing in semiconductors. The Microelectronics Research Center (MRC) is addressing research issues of importance to semiconductor materials and devices, in conjunction with faculty and students in the Center for Materials Science and Engineering (MS&E), Manufacturing Systems Engineering, Electrical and Computer Engineering, Chemistry, and Physics. The faculty and graduate students are working on the materials necessary for the next generation of integrated circuits and optoelectronic systems, advanced crystal growth (with control at the atomic layer dimension) of complex structures for semiconductor lasers, detectors, and modulators for photonic systems, optical interconnects, and novel microwave and

millimeter wave devices. They are also involved in advanced packaging research, which is of paramount importance to the successful use of devices in systems, and an area which has been largely dominated by Japan.

The funding from DoD has been used to facilitate the research of 11 faculty in the Microelectronics Research Center, who specialize in semiconductors. The faculty and graduate students are working on the materials necessary for the next generation of integrated circuits and optoelectronic systems, advanced crystal growth (with control at the atomic layer dimension) of complex structures for semiconductor lasers, detectors, and modulators for photonic systems, and novel microwave and millimeter wave devices. Researchers at UT are also studying optical interconnects, which is potentially a breakthrough technology for very large computer systems.

Significant research support in the area of microelectronics at The University of Texas at Austin has been obtained from the Department of Defense, the National Science Foundation, the Advanced Research Projects Agency, the Texas Advanced Research and Technology Programs, and from industry. The MRC has been designated a SEMATECH Center of Excellence and a site for an NSF Science and Technology Center, a DoD Joint Services Electronics Program, an ARPA Optoelectronics Center (jointly with Illinois and Michigan), and an ONR Multi-University Research Initiative site (jointly with Purdue, RPI, Howard, and Cray Research. The MRC has one of the largest and most diverse

semiconductor research programs at any university in the country, and the 11 faculty in the Microelectronics Research Center include 3 members of the National Academy of Engineering, 4 NSF Presidential Young Investigators, and an Office of Naval Research Young Investigator.

In 1993, the Microelectronics Research Center moved into a new facility at the J.J. Pickle Research Campus, the Microelectronics and Engineering Research Building. This facility includes cleanrooms, chemical and gas handling capabilities, testing and evaluation laboratories, and office space for approximately 15 faculty and 120 graduate students in microelectronics and related research. This facility provides an outstanding environment for semiconductor materials and device research and allows the faculty and students in Microelectronics to develop strong interdisciplinary programs. The DoD support of equipment has made this facility exceptionally well suited for performing forefront research in the materials and devices required in future generations of electronic and optoelectronic systems.

In the materials science area, the DoD funds have been used in several completed and ongoing projects in the Laboratory for Smart Materials and Devices. The electron beam deposition system is used primarily to deposit: (a) elemental and alloy, single and mutilayer, polycrystalline, metal and nonmetal thin films, (b) refractory metal alloys (e.g. molybdenum, titanium) over photoresist for liftoff processing of integrated devices and, (c) gold-

chromium electrical contacts to integrated devices. The ion beam etching/deposition system is used to: (a) sequentially sputter, and co-sputter deposit both elemental and alloy, single and multilayer, polycrystalline and amorphous, metal and nonmetal thin films, (b) fabricate compositionally modulated thin films with modulation periods in the 5Å - 30Å range, and (c) to transfer micron scale patterns to lithographed devices by reactive etching and ion milling, and (d) to synthesize thin films by ion-beam assisted sputtering deposition.

Three examples are provided showing the research system developed through the use of the DoD funds: the X-ray Diffractometer System, the Microscope and Workstation System, and the E-Gun Control and Electron Microscope System.

1) X-ray Diffractometer System

This system is a high-intensity, high-resolution x-ray diffractometer designed to meet specific research requirements for quantitative measurements of thermal stresses in submicron interconnect metallization and structure analysis of polymer and metal thin films and layers structures as a function of temperature and controlled atmosphere. It is equipped with independent motion of the x-ray source and the detector, a

position-sensitive detector and computer-controlled sample holder with heating capability.

2) Microscope and Workstation System

The scanning tunneling microscope was purchased to investigate the molecular morphology and conformation of polymer surfaces and interfaces. This instrument is equipped with computer image processing capability and can be compatible with high-vacuum operation.

3) E-Gun Control and Electron Microscope System

The purpose of this system is for microstructure characterization of submicron metal lines. Microstructures, such as the grain boundaries, play an important role in defining the path of mass transport and the nature of damage formation process.

The following is a brief description of four examples of the projects on which some of the DoD equipment is being utilized in the materials science area:

1) Integrated and Fiber Optic - Magnetostrictive Magnetic Field Sensors (Sponsor: Texas ATP)

This project is concerned with the development of a new type of magnetic sensor in which the flux from a magnetic field is sensed by causing a magnetostrictive film to strain an integrated or fiber optic sensor. The electron beam system is being used to develop and integrated highly magnetostrictive, multilayers of CoFe/NiFe alloy thin films. This project is concerned with the development of a new type of integrated magnetic sensor for use in imaging eddy current induced magnetic fields in non-destructive testing. The ion beam system is being used in the fabrication of this device; principally for ion-milling the integrated optic interferometer sensor, and for deposition of the electrical contacts to the device.

2) Development of GHz Integrated Inductors (Sponsor: I/UCRC for Magnetics/WPAFB)

The goal of this project is to develop microelectronic magnetic thin film inductors that are process compatible for integration into GaAs telecommunication circuits. The electron beam system is being used to fabricate and study several types of

rare earth doped transition metal alloy thin films. These films will be integrated into microfabricated inductors for subsequent characterization in the 1-3 GHz frequency range. The goal of this project is to develop microelectronic magnetic thin film inductors that are process compatible for integration into 1-3 GHz GaAs telecommunication circuits. The ion beam system is being used in the fabrication of this device, including the initial metallization liftoff and the final ion milling etch processing steps.

3) Laminated Magnetic Film Particles (Sponsor: General Atomics/USAF)

This is a study of the microwave response (1GHz-10GHz) of micron-scale, laminated magnetic CoFe thin film particles consisting of alternating ferromagnetic and insulating layers. These particles have considerable interest for use in a variety of microwave devices. The electron beam system will be used to deposit the laminated particles. This is a study of the microwave response (1GHz-10GHz) of micron-scale, laminated magnetic thin film particles consisting of alternating ferromagnetic and insulating layers. The ion beam system is being used to fabricate

arrays of micron-scale, elliptical, laminated particles for microwave characterization and optimization.

4) Antenna Loading Materials (Sponsor: California Microwave Inc.)

Research is being conducted on a new type of microwave composite for use in miniaturizing the size of cavity-backed antennas for applications in the 100 MHz - 1 GHz frequency range. These composites are fabricated from multilayers consisting of alternating ferromagnetic and insulating thin films. The composites are designed to have low electromagnetic losses, unity wave impedances, and indices of refraction ~100. These properties will permit an order of magnitude reduction in the size of the cavities used to increase the gain of antennas over ground planes. Experimental studies are being conducted with candidate multilayer film systems deposited in the ion beam and electron beam sputtering systems. Parallel efforts are underway to transfer the results of this research to a commercial roll coater deposition facility.

A detailed listing of the equipment purchased using these funds appears on the following pages.

II.1. **Original Listing of Equipment Requested**

Item No.	Equipment Name	Estimated Cost (Thousands of $'s)	Brief Explanation
1	Reactive ion etching and cleaning	$560	Precisely controlled etching of compound semiconductors is essential to the fabrication of the present and future generations of advanced device structures.
2	Physical and chemical deposition	460	Deposition of oxide and nitride layers by plasma-assisted chemical vapor deposition is a key processing technology. Silicidation, metal sputtering and deposition of metals for ohmic contacts is required for all devices to be studied.
3	Epitaxial growth	980	Includes systems for growth of thin films by MBE, CBE, MOCVD, and multiprocessing using plasma and laser enhanced CVD.
4	Rapid thermal processing	500	Four rapid thermal processing systems for silicon and compounds to allow device fabrication and processing with low thermal budget to maintain integrity of multilayer structures and doping profiles.
5	Diffusion and oxidation	130	Used to perform device processing steps.
6	Device characterization	400	Used to characterize light-emitting devices. Includes optical bench, optical spectrum analyzer, high resolution spectrometer with computer interface, temperature controlled dewar, associated electronics and a Ti-sapphire laser for optical excitation.
7	Optical characterization	550	Microscopes, ring laser, and Fourier-transform infrared spectrometer to optically characterize semiconductor materials.
8	Mask making	520	Used to produce and examine lithography masks of moderate feature size
9	X-ray diffractometer	440	A high-resolution x-ray diffractometer with accessories including stress measurements of fine line metallization and structure analysis of polymer and metal thin films and layered structures as a function of temperature and controlled atmosphere.

10	Scanning tunneling and atomic force microscope	160	Used to investigate the molecular morphology and conformation of polymer surfaces and interfaces. This instrument will be equipped with computer image processing capability and can be compatible with high-vacuum operation.
11	Packaging equipment	100	Wire bonder system for device physics research.
12	Computer equipment	250	Power station/servers, workstations, and a parallel architecture computer.
13	Laboratory support equipment	350	Cryogenic dewars, safety equipment, process tools, equipment transport carts, and machine tools.
14	Computer process controlled, multisource electron beam, UHV thin film evaporator	340	An evaporator of this type is required to deposit multilayer thin films and compositionally modulated structures with wavelengths in the 10-100 A range.
15	Multiple source, chemically assisted ion beam etching/milling system	260	Will be used to process a variety of laterally constrained nanostructures for magnetic, electronic, and optical applications.
	TOTAL	**$ 6,000**	

II.2. Changes to Equipment List

In developing research interactions with colleagues in industry we have found that it is important to use silicon wafers which are compatible with present-day processing equipment. In the past we have been restricted to 4-inch wafers due to the size of our furnaces used for diffusion, oxidation, and deposition. Recent experience shows that using wafers smaller than six inches in diameter causes problems in interactions with industrial colleagues, because their processing equipment is designed for 6 or 8 inch wafers.

In order to upgrade our furnace system from 4" to 6", funds were transferred from other categories into items 2 (deposition) and 5 (diffusion and oxidation) as follows:

- $370K transferred from Item #4 to Item #2.
- $160K transferred from Item #1 to Item #2.
- $130K transferred from Item #3 to Item #5.
- $27K transferred from Item #7 to Item #5.

- The computer equipment requested in Item #10 was purchased at a discount, which allowed us to transfer funds into item 11 to upgrade our laboratory support facilities, including the machine shop used by our students.

- $132K transferred from Item #10 to Item #11.

- The remainder in Item #6 ($165K), Item #7 ($49K), Item #8 ($14.7K) and Item #9 ($83.5K) was used for fitup and miscellaneous parts.

II.3. Equipment Purchased

Item No.	Equipment Name	Cost	Manufacturer
1	Reactive ion etching and cleaning:		
	Reactive Ion Etch System	400,075	Plasma-Therm
2	Physical and chemical deposition:		
	High Vacuum Deposition System	161,842	CHA Industries
	Pulse Generator	43,845	Hewlitt Packard
	Regenerative Amplifier for Laser System	95,000	Coherent Laser Group
	Furnace System	313,645	MRL Industries
	Anatech Hummer Sputter Coater	8,032	EM Corp.
	Profilometer	33,900	Telesis High Vacuum Inc.
	Flow Loop Manifold	3,225	MRL Industries
	Supersystem Series Deposition System	272,260	Kurt J. Leskar Co.
	Sterilizing Quartz Cleaner Cabinet	41,517	Wafer Process Systems
	Plasmatherm Channels	6,732	Gas Tech, Inc.
	Subtotal	979,998	
3	Epitaxial growth:		
	Turpo Pump, Roughing Pump, Gate	44,746	Varian Associates, Inc.
	Valve, Feedthroughs, Clamps	1,702	National Instruments
	Labview Applications Builder	7,124	Corp.
	Power Feedthroughs	3,028	Insulator Seal Inc.
	Heating Element	12,580	Advanced Ceramics Corp.
	Mass Spectrometer	7,103	UTI Instruments
	Rotary Motion Feedthroughs	2,936	THT Sales Co.
	Recirculating Bath	15,467	Neslab Instruments
	Filaments	202,096	Advanced Ceramics Corp.
	Furnace System	2,327	MRL Industries
	Custom UHV Chamber	297,379	Kurt J. Lesker Co.
	Multi Wafer High Temp Disc	130,850	Emcore Corp.
	Molecular Beam Epitaxy System	50,792	AT&T
	Buffer/Transistion Chamber Kits	2,104	Chorus Corp.
	Cryopump Monitor	7,011	Lake Shore Cryotronics,
	Refrigerated Recirculator	47,042	Inc.
	Accessories, Gases, Manuals, etc.	15,509	Neslab Instruments Inc.
			Vacuum Barrier Corp.
		847,795	Kinetic Systems Inc.
	Subtotal		

4	Rapid thermal processing:		
	Rapid thermal processor	63,213	AET Thermal
	Rapid thermal annealer	66,484	AG Associates
	Subtotal	129,697	
5	Diffusion and oxidation:		
	Furnace System	286,758	MRL Industries
6	Device characterization:		
	Camera System	146,038	Hamamatsu Corp.
	Optical Spectrum Analyzer	64,506	Hewlett Packard
	Optical Spectrum Analyzer	24,300	Colcom Inc.
	Subtotal	234,844	
7	Optical characterization:		
	Laser	154,493	Coherent Laser Group
	Time Bases	13,281	Schonfeld
	Spectrum Analyzer	42,167	Hewlett Packard
	Computer	1,976	Caliber Computer Corp.
	IR Camera System	12,655	Hamamatsu Corp.
	Power Macintoshes	4,182	Texas Union MicroCenter
	Microscope Systems	48,428	Leeds Instruments, Inc.
	Lock Laser	34,779	Clark-MXR Inc.
	Lasers	33,258	New Focus Inc.
	3-D Imager	6,024	Spiricon Inc.
	Lasers	11,207	Santa Fe Laser Co.
	Optical Transmitter and Receiver	4,552	Force Inc.
	Rotator and Controller	6,242	Polytec PI Inc.
	Microscope	25,915	Olympus Corp.
	Lasers and accessories	16,900	Newport Corp.
	Translation Stages	10,430	Thorlabs Inc./Newport Corp.
	Vertical cabinets	1,361	Baxter Diagnostics, Inc.
	IR Viewer, Filter	1,655	FJW Optical Systems Inc.
	Rotation Stage	4,280	Polytec PI Inc.
	Optical Cryostat System	13,441	Janis Research Co. Inc.
	Spectrometer	39,033	Nicolet Instrument Corp.
	Subtotal	486,259	

8	Mask making: Micro Pattern Generator Confocal Scanning Microscope Subtotal	 331,750 173,576 505,326	 Research Devices Inc. Nikon Instrument Group
9	X-ray diffractometer: Ultrasonic Wire Bonder & Tool Assembly	 16,490	 West Bond Inc.
10	Scanning tunneling and atomic force microscope: Workstations Supercomputer Station Printer Power Macintosh Printer Cabletron Digital Film Recorder Subtotal	 297,477 52,985 7,994 4,891 2,088 11,238 5,362 382,035	 IBM Corp. Intel Corp. Austin Business Computers Texas Union MicroCenter Texas Union MicroCenter Sabre Data Inc. Metallurgical Supply Co.
11	Packaging equipment: Nitrogen vessel and components	 481,596	 Southland Cryogenics Inc.
12	Computer equipment: IBM Computer Microscope & Workstation Subtotal	 36,817 100,000 136,817	 IBM Corp. Digital Instr.
13	Laboratory support equipment: X-Ray Diffractometer System Electron microscope Mechanical analyzer Subtotal	 242,500 185,408 45,000 572,908	 Rigaki Inc. USA Inc. Rheometrics Inc.

14	Computer process controlled, multisource electron beam, UHV thin film evaporator: Electron beam evaporation system	265,521	Innotec Group Inc.
15	Multiple source, chemically assisted ion beam etching/milling system: Ion beam etching sputtering system	334,367	Oxford Instruments North
	TOTAL (Amount above $6 mil was paid for out of other University accounts.)	**$6,060,486**	